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INDIGENT PRODUCTION OF NON-DISTORTED ISARITHMIC MAPS BY RASTER CONTOURING

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ABSTRACT
The traditional method of using a conventional line-printer to produce rough isolines using raster contouring techniques in indigent environments is reviewed. It is suggested that methods where the isolines are boundaries between different symbols and having no thickness are better, and that numeric (hexadecimal) characters are best used to represent different levels of the dependent variable, especially where the slope of the surface is high. A comprehensive solution is also found to the usual problem with line-printer maps of distortion due to unequal scales in the two axes of the coordinate system. The contouring procedure is easily adaptable for use by indigent researchers or in indigent environments for all areal phenomena.

KEYWORDS: *computer mapping, raster plotting, isopleths, line-printer maps, monospaced fonts*

INTRODUCTION

In many two-dimensional (areal) studies, it is often very useful to present the data in form of some sort of contours or isopleths, which are used to display levels of the dependent variable over the area. Contouring has been a traditional and highly efficient technique for presenting information visually.

In one-dimensional surveys, a curve may be fitted visually to the readings and the function value interpolated directly from the plot. However, one can rarely visualize contour lines directly from two-dimensional (areal) data; hence interpolation is used to locate the contours.

The basic assumption of all spatial estimation (Philip and Watson, 1986) is that there exists a mathematical function underlying the empirical measurements made at the different locations. (In most investigations, the data points are discrete, whether regularly-gridded or irregularly-spaced.) To fit a surface to the measured values, a continuous, two-dimensional interpolation function, approximating or fitting exactly the given values at the data points, is usually defined in the plane. It may also happen that in the course of investigations into some physical phenomena a function defining a theoretical surface is produced. In either of these cases, it may be desirable to display the surface in some sort of contour map or perspective view.

TWO-DIMENSIONAL INTERPOLATION PROCEDURES

Computer contouring inevitably requires the implementation of one or more two-dimensional interpolation procedures. There are many schemes available, depending on whether the data points are regularly-gridded or irregularly-spaced.

Most vector contouring procedures require the values of the dependent variable over a regular grid as the starting position. If an investigator has control over the location of data points, he can array them in a lattice or grid, with a uniform spacing between points. The contours can then be plotted directly from these gridded values by vector contouring procedures. Alternatively, for purposes of raster contouring, values of the dependent variable at all other points in the plane can thereafter be estimated from the gridded values by a suitable interpolation procedure. In that case, interpolation can be accomplished easily by a number of established methods, which are purely exact, i.e. the interpolated values coincide with the known values at the data points. An overview of these numerous methods is given in Okunade (1998).

In certain investigations, as in soil surveys for instance, usually, the location of data points is beyond the control of the investigator and does not correspond to any geometric pattern. In these and similar cases the investigator must cope with irregularly-spaced data points. Here, interpolation procedures exist which are used to generate the ultimate gridded values at the mesh-points of an imposed regular grid used for contouring. Okunade (1998) has given a comprehensive overview of these procedures. The contours can then be plotted directly from these gridded values by vector contouring procedures. Alternatively, values of the dependent variable over the whole plane can also be estimated from the obtained gridded values using the same interpolation procedure used to generate the gridded values or a different one, which is simpler and faster. Many investigators have done this in the past. For example, one may use the full (primary) interpolation algorithm at regular grid points representing a fraction (a sixth) of the total locations (every third horizontal and every second vertical location). Simple linear interpolation using Newton's divided differences formula for the surrounding four points can then used for the intervening points. This increases computational speed without having any significant effect on the nature of the interpolated surface.

Table 1: RESOLUTIONS OBTAINABLE FOR CATEGORY A FONTS (WITH RESOLUTION OF THE 12 POINT SIZE AT 10 CHARACTERS PER INCH)

FONT SIZE (points)	LINE SPACING OR LEADING (points)	RESOLUTION	
		(characters per inch)	(characters per centimeter)
14	8.4	8.57	3.37
13	7.8	9.23	3.63
12	7.2	10.00	3.94
11	6.6	10.91	4.29
10	6.0	12.00	4.72
9	5.4	13.33	5.25
8	4.8	15.00	5.91
7	4.2	17.14	6.75
6	3.6	20.00	7.87
5	3.0	24.00	9.49
4	2.4	30.00	11.81

For irregularly-spaced data, schemes also exist which calculate values of the dependent variable over the whole plane directly from the initial irregularly-spaced data, without first generating values over a regular grid.

In the case of a function defining a theoretical surface already existing, it is not difficult to either generate values at mesh-points of an imposed grid to be used for contour plotting, or at all locations over the whole plane as may be required.

COMPUTER CONTOURING TECHNIQUES

Vector Method of Contour Representation

When using vector contouring techniques, the problem of computer contouring can be considered separately in terms of the calculation of the location of the individual line segments, and the logic of the drawing of all the segments. Straight-line segments are sometimes used, but more preferable, though more difficult, is the production of continuous curved lines.

Many schemes have been proposed for plotting contours using vector contouring techniques. Details of these have been provided in Okunade (1998). Most automatic contouring schemes generate a regular grid prior to contouring. Some then complete the interpolation by drawing the contours directly, using an interpolation formula or surface within each grid square. The original data points that do not lie on the grid are neglected after the grid has been constructed. This approach obviously does not honour every data point for irregularly-spaced data. Other schemes complete the interpolation by calculating interpolated values for all the cells within each grid square before embarking on the contouring process using an appropriate contour encoding algorithm, e.g. the one proposed by Gonzalez and Wintz (1987).

One could also have contouring without a preliminary regular grid, though. Without a grid, contouring may be done directly through a triangulation of the data points (Lowden, 1985; Sawkar *et al*, 1987).

The problem with the contouring methods mentioned above is that they require a special and costly hardware configuration. In most cases a digital plotter and a very large storage capacity are required. They are also unusually inefficient and very slow for a mechanical graphic output device. Most of the methods draw the contours as a series of straight line segments. Producing smooth, accurate contours requires small grid cells; otherwise the contours are jagged.

The highly technical and costly equipment required with these methods are often not easily affordable for most independent investigators, or in indigent environments. This is not the case when using the computer to plot contours using raster displays produced on a conventional printer.

Table 2: RESOLUTIONS OBTAINABLE FOR CATEGORY B FONTS (WITH RESOLUTION OF THE 12 POINT SIZE AT 12 CHARACTERS PER INCH)

FONT SIZE (points)	LINE SPACING OR LEADING (points)	RESOLUTION	
		(characters per inch)	(characters per centimeter)
14	7.0	10.29	4.05
13	6.5	11.08	4.36
12	6.0	12.00	4.72
11	5.5	13.09	5.15
10	5.0	14.40	5.67
9	4.5	16.00	6.30
8	4.0	18.00	7.09
7	3.5	20.57	8.10
6	3.0	24.00	9.45
5	2.5	28.80	11.33
4	2.0	36.00	14.17

Raster Method of Contour Representation

Another means of producing isarithmic maps of continuous geographic data matrices apart from using the computer to produce vector displays on a pen plotter is by using the computer to produce crude raster displays on the line printer (Eyton, 1984). Many investigators have used this method to display contours of an areally distributed data in their work. Various such works are mentioned in Okunade (1998).

In this method, the map area must have been divided into a series of unit cells, each cell being the size of a printer character. Also, the interpolation must have been completed prior to contouring for all the cells of the whole plane using either a single interpolation formula throughout or combined methods as described earlier.

There are two ways in which contour lines can be portrayed using raster mapping techniques:

a) As lines having a width equal to one unit cell of the map area. The variable value for each cell is calculated using an appropriate interpolation formula. The class or variable range to which each cell belongs is then ascertained. All cells are left blank except class boundaries which are made to contain the printer characters representing that class. The class boundaries are found by comparing the class of each unit cell to the classes of neighbouring cells using the criteria given by Eyton (1984). The disadvantage of this method is the imposition of a minimum useable contour interval. If the contour interval is too small it will cause characters (contour lines) to be lost in high gradient areas where the contours must be closer than the normal printer character spacing allows.

b) As boundaries (having no width) between differently shaded or differently marked variable classes. Every cell is assigned its respective symbol, except in areas with insufficient nearby data points to warrant interpolation and where “no value” has been assigned to the cell. The characters available on a computer printer are used to give different shading levels representing the different classes of the variable. Various shades can be obtained from these characters to suit the user. Scales using density character sets (., -, /, +, *, $, &, etc.) or numerals (0, 1, 2, ... , 9) may be used, where darker symbols or higher digits usually denote higher values of the dependent variable. (Using a numeric scale is somewhat better in that it easily shows if any levels are missing or not depicted between two neighbouring cells, especially where the slope of the surface is high, and hexadecimal characters permit more numerous levels of the dependent variable to be depicted.) For these line-printer maps to be suitable for publication, the contours (boundaries between different symbols) may be traced and smoothed by hand and then superimposed on the base maps which are the hand-prepared outlines of the geographical boundaries of the map units and some of the major landmarks. The major advantage of this approach is that there is no imposed minimum useable contour interval since the continuity of the contour lines can be maintained while smoothing by hand. This is the approach recommended in this study.

Table 3: RESOLUTIONS OBTAINABLE FOR CATEGORY C FONTS (WITH RESOLUTION OF THE 12 POINT SIZE AT 15 CHARACTERS PER INCH)

FONT SIZE (points)	LINE SPACING OR LEADING (points)	RESOLUTION	
		(characters per inch)	(characters per centimeter)
14	5.6	12.86	5.06
13	5.2	13.85	5.45
12	4.8	15.00	5.91
11	4.4	16.36	6.44
10	4.0	18.00	7.09
9	3.6	20.00	7.87
8	3.2	22.50	8.86
7	2.8	25.71	10.12
6	2.4	30.00	11.81
5	2.0	36.00	14.17
4	1.6	45.00	17.72

In either of the two methods above, a two-dimensional array would be generated containing the character to print (blank or otherwise) for each cell on the map.

In general, producing maps on a standard line printer with detail equal to the width of a print character using symbols to indicate the interpolated values requires no special hardware configurations. This is a unique advantage in terms of ease and cost of production, and making it a convenient approach in indigent environments, and where researchers must compensate for their indigence. In practice (Crain, 1970), choice of an interpolation and contouring method depends on the nature and ultimate purpose of the data, and the particular hardware configuration available. Using a standard line printer, the data for each row of the map are sent to the printer one after another using an appropriate programming language.

The Problem of Distortion in Line-Printer Maps

The problem with line printer maps, usually, is that the horizontal dimension (pitch) of a print character (cell) is different from the vertical dimension (line spacing). Horizontally, we usually have a pitch of 10 characters per inch (i.e. a cell dimension of one-tenth of an inch) and a vertical line spacing of 6 characters per inch (i.e. a cell dimension of one-sixth of an inch). This results in a distortion of the map because the horizontal scale is different from the vertical scale, as evident from the works of many investigators in the literature. The scales could be normalized prior to plotting but this would involve some complications. The solution proposed by the author is that the section of the computer programme to print out the map should contain a portion coded to initialize the printer for a line spacing equal to, or approximately equal to, one-tenth of an inch. Depending on the printer used, an escape sequence, coded in the selected programming language, is sent to the printer to initialize it to a line spacing of one-tenth, or approximately one-tenth, of an inch, thereby setting the vertical spacing to be equal to the horizontal print pitch. Such printers include some EPSON printers and the IBM Proprinter.

Escape sequences for EPSON ESC/P and ESC/P 2 printers (SEIKO EPSON Corporation, 1997) have been developed for 9-pin dot-matrix and 24/48-pin dot-matrix printers. The monospaced (i.e. equal-pitch) characters readily available on these printers have horizontal pitches or character spacings of 10, 12 or 15 characters per inch. The escape sequence "ESC 3 n" (in ASCII) sets the line spacing equal to n/216-inch for 9-pin dot matrix printers and n/180-inch for 24/48-pin dot-matrix printers. Choosing an appropriate value of n, depending on the character pitch and printer selected, gives a line spacing equal or approximately equal to the horizontal pitch, thereby resulting in a non-distorted map.

More Refined Printer Outputs

More refined output can be produced from either the line printer or printers other than the line-printer, e.g. page printers such as laserjet or deskjet printers. The array containing the map information is imported whole into any of the more sophisticated word-processing applications. The output is then sent to the printer at once in a monospaced (equal-pitch) font.

For the monospaced (equal-pitch) typefaces, the font size is inversely proportional to the resolution of the print. If the font size (in points) is denoted by s, and the resolution (in characters per inch) is denoted by c, then

$$c \propto \frac{1}{s} \tag{1}$$

or

$$c.s = k \tag{2}$$

Therefore, if the resolution, c_1 (characters per inch), is known for any given font size s_1, the resolution c_2 can be determined for any other font size s_2 of the same typeface.

$$c_2 = \frac{s_1.c_1}{s_2} \tag{3}$$

The horizontal spacing (pitch), p, of the characters is given by $\frac{1}{c}$ (in inches) or $\frac{72}{c}$ (in points), since 1 inch = 72 points. If the resolution, c_1 (characters per inch), is known for any given font size s_1, the pitch, p_1, for that font size or p_2 for any other font size s_2 of the same typeface can be determined from:

$$p_1 = \frac{1}{c_1},\ p_2 = \frac{s_2}{s_1.c_1} \text{ (in inches)} \tag{4}$$

$$p_1 = \frac{72}{c_1},\ p_2 = \frac{72s_2}{s_1.c_1} \text{ (in points)} \tag{5}$$

To avoid distortion due to the horizontal scale being different from the vertical scale, the vertical spacing (line spacing) of the print must be fixed to be equal to the calculated value of the pitch for the particular font size. The line spacing or leading can be fixed in some word-processing applications (such as Microsoft Word, Adobe Pagemaker, WordPerfect, etc.) to a precision of one-tenth of a point, a point being one-seventy second of an inch.

For certain typefaces (Category A), the resolution for the 12 points font size is 10 characters per inch. Therefore, the resolution for any other font size s of such typefaces will be $\frac{12\times10}{s}$ or $\frac{120}{s}$ (characters per inch), while the pitch will be $\frac{s}{120}$ (inches) or $\frac{72s}{120}$ = 0.6*s* (points). Such typefaces include the Courier New, Courier10 BT, CourierPS, CentSchbook Mono BT, Lucida Console, Monospac821 BT, Orator10 BT, Pica10 BT, Prestige12 BT, OCR A Extended, and OCR-B 10 BT.

For certain other typefaces (Category B), the resolution for the 12 points font size is 12 characters per inch. Therefore, the resolution for any other font size s of such typefaces will be $\frac{12\times12}{s}$ or $\frac{144}{s}$ (characters per inch), while the pitch will be $\frac{s}{144}$ (inches) or $\frac{72s}{144}$ = 0.5*s* (points). Such typefaces include the Letter Gothic and the LetterGoth12 BT typefaces.

For yet certain other typefaces (Category C), the resolution for the 12 points font size is 15 characters per inch. Therefore, the resolution for any other font size s of such typefaces will be $\frac{12\times15}{s}$ or $\frac{180}{s}$ (characters per inch), while the pitch will be $\frac{s}{180}$ (inches) or $\frac{72s}{180}$ = 0.4*s* (points). Such typefaces include the Orator15 BT typeface.

Depending on the typeface selected and the font size chosen, different resolutions of the printed map are possible, as indicated in Tables 1, 2 and 3.

In most of the above configurations, the cap height of the print character is equal to, or approximately equal to, the specified vertical line spacings, thereby producing maps with an even density of the print characters over the area of the map, with the bottom of a print character just touching the top of the one underneath it, the lines thus having little or no leading (the vertical space between lines of type in a paragraph). However, for some fonts, the Orator15 BT font for example, the cap height is much higher than the required line spacing corresponding to the font size to give a non-distorted map. This results in the print characters overlapping vertically.

For geographical phenomena, the isarithmic maps will ultimately be superimposed on the base maps, which will have been produced at specified scales. Therefore, it is necessary to be able to produce the isarithmic maps at a scale or resolution corresponding to the existing base map, which resolution may not be among those in the tables above. The font size to be used to produce more exact specified resolutions (characters per inch or characters per centimeter) different from those in the tables above may be obtained from Equation (1), i.e. $c_2 = \frac{s_1.c_1}{s_2}$, or

$$s_2 = \frac{s_1.c_1}{c_2} \tag{6}$$

(s_i in points and c_i in characters per inch or characters per centimeter). The quantity $s_1.c_1$ has different values depending on the font family, but constant for each font family. The pitch or vertical line spacing (in points) is then obtained from $p = 0.6s$, $p = 0.5s$, and $p = 0.4s$ for Category A, Category B, and Category C fonts, respectively. The font size and line spacing (or leading) obtained may not be integral, but this can be fixed to an accuracy of 0.1 point for both the point size and the leading, those being the respective nudge amounts for the font size and line spacing in some word-processing applications, e.g., Adobe Pagemaker. (For Microsoft Word, the nudge amount for the point size is 0.5 point, but 0.1 point for the leading.)

The raster contouring procedure described in this study is the one employed in an extensive engineering soil mapping programme in Nigeria (Okunade, 1998). An example of such maps is shown in Figure 1. The contouring procedure was found to be cheap and on machines that are easily available in an indigent environment. It will be useful for other areal phenomena in the fields of Engineering and the Geosciences.

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ISARITHMS OF MAXIMUM DRY DENSITY FOR BENDEL STATE (kg/m^3)

LEVEL:	1	2	3	4	5	6	7	8	9
MIN. VALUE:	1400	1501	1601	1701	1801	1901	2001	2101	2201
MAX. VALUE:	1500	1600	1700	1800	1900	2000	2100	2200	2300
SYMBOLS	22222	33333	44444	55555	66666	77777	88888	99999	AAAAA

(* = data point)

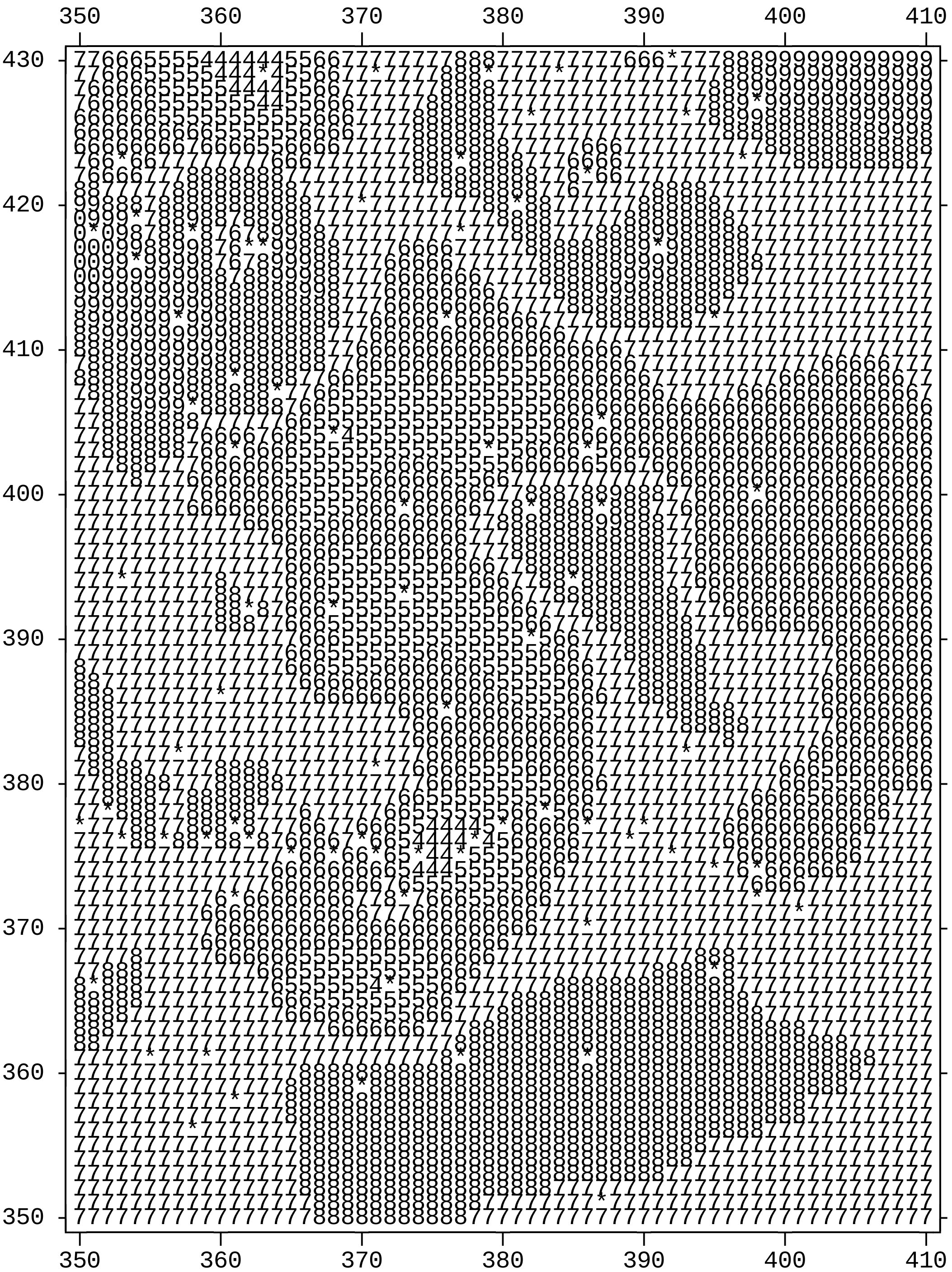

Figure 1: Example of Isarithmic Map Produced from Raster Contouring